Removal of ballistocardiographic artefact from EEG-fMRI data: a canonical correlation approach

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I. Introduction

Nowadays there is no technique able to simultaneously achieve the high temporal resolution of Electroencephalogram (EEG) and the good spatial resolution of functional Magnetic Resonance Imaging (fMRI). With the currently available technology the only way of obtaining high temporal and spatial resolution with non-invasive procedures is to combine EEG and fMRI. When EEG and fMRI are combined, the interaction between the magnetic fields, electric currents and the human body generates artifacts. In particular, the ballistocardiographic artifact (BCGa) that appears on the EEG is believed to be related to blood flow in scalp arteries leading to electrode movements. In this work the removal of the BCGa is addressed. Different methods have been proposed to remove the BCGa, based either on Blind Source Separation (BSS) or averaging techniques [1]. We present a BSS approach based on Canonical Correlation Analysis (CCA) [2] that uses characteristics of the BCGa in both the spatial and the temporal domain. We demonstrate that our method deals with the intrinsic subject variability specific to the artefact that may cause averaging techniques to fail.

II. Method

Data: Five epileptic subjects underwent an EEG-fMRI experiment of variable duration [3]. The subjects were asked to rest with eyes closed. Recordings were performed inside and outside a 1.5 T MR scanner (GYROSCAN ACS-NT, Philips, Best, the Netherlands). One additional subject performed the same task in a 3 T scanner (ACHIEVA, Philips, Best, the Netherlands). The EEG equipment (SD-MRI, Micromed, Mogliano Veneto, Italy) consisted of an fMRI compatible headbox and a 32 silver ring electrode cap, with electrodes positioned according to the standard 10-20 international system. Signals were recorded in 31 unipolar EEG channels plus one additional bipolar ECG.

Theoretical background: In BSS the signal is modeled as a linear combination of sources: $x = As$, where x is a (M-by-N) matrix containing the time series recorded through M sensors, A is the (M-by-M) unknown mixing matrix and s is the (M-by-N) matrix containing the time course of the sources. When constraints are imposed to s, BSS estimates the unmixing matrix from which the sources can be recovered. After identifying and eliminating the artifact sources, a cleaned signal can be reconstructed. It has been proven [4] that Canonical Correlation Analysis (CCA) can be interpreted as a BSS technique able to extract underlying sources from the data, by maximizing their temporal correlation. Here we apply CCA to find those maximally temporally correlated sources within two consecutive windows centered on two consecutive artifacts. The artifact sources are then selected according to their cross-correlation over time, in order to match the main characteristic of the BCGa.

The results are evaluated versus an Average Artifact Subtraction technique (AAS), used as ref-

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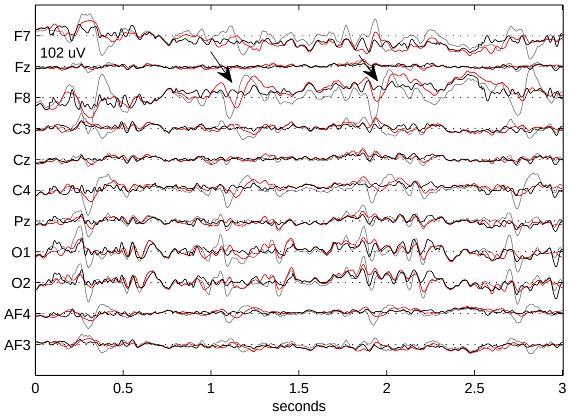

Figure 1. Comparison of EEG fragments before (gray line), and after artefact removal with AAS (red line) and CCA (black line). The arrows mark points where the AAS left residual of the artefact.

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III. Experimental results

We used several measures to validate the proposed method: on one hand, we used average quantities, such as the mean extracted artefact or the power spectral density, to evaluate the effect of the inter-subject variability; on the other hand measures based on the single artefact occurrence are considered. These measures are more sensitive to the intra-subject variability. When tested on several subjects, the average artefact extracted with BSS-CCA and AAS did not show significant differences, proving the absence of systematic errors. On the other hand, when compared on the basis of intra-subject variability, we found significant differences and better performances of the proposed method with respect to AAS. Figure 1 shows a superposition of an EEG fragments before and after artefact removal with AAS and CCA, for a subset of channels. We see that while AAS leaves some residual BCGa's, marked by arrows, this is not the case for CCA.

IV. Conclusion

In this work, both temporal and spatial characteristics of the BCGa are used to estimate the contaminating sources and to identify the artifact. We demonstrated that CCA can be a valuable tool in removing the BCGa from simultaneous EEG-fMRI recording. Our method deals with the intrinsic subject variability of the artifact that may cause averaging techniques to fail.

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